Three-dimensional-dosimetry of ionizing radiation on a microscopic scale using parameter selective MRI

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Introduction/Purpose

3D-dosimetry of narrow beams of ionizing radiation can hardly be performed due to the large size of ionization chambers or the limitation to 2 dimensions with film dosimetry. The accurate determination of 3D-dose distributions becomes increasingly important with the upcoming new methods for radiation therapy with fine dose localization, for instance micro-multileaf intensity modulated radiation therapy (IMRT), "γ-knife"-treatment or proton therapy. MRI-based polymer dosimetry has proved its capacity to visualize 3D-dose distributions [1] but yet the spatial resolution on clinical MRI-scanners has been limited to about 1 x 1 x 3 mm^3. We show here for the first time that it is possible to visualize distinct dose levels at spatial separation of 200 µm by MRI. As an application we present 3D-dosimetric images of a very narrow electron beam at a diameter of 2 mm in tissue equivalent absorber material.

Materials and methods

MRI based polymer dosimetry (MRPD) is based on the sensitivity of the transverse relaxation time T2 to the immobilzation of polymer-protons which accompanies the polimerization process of monomers induced by irradiation. We use a self prepared "normoxic" polymer (methacrylic acid) gel recipe based on an oxygen-scavenger (tetrakis-hydroxy-methyl-phosphonium-chloride) in order to avoid polimerization suppression by oxygen [2]. For proving the spatial resolution of MRPD very fine dose modulations are obtained using an absorption mask in a gamma radiation beam (Co60, Theratron, radiation field: 10x10 cm^2). The absorption structure consists of three spatial grids ranging from a half period of a/2=200 µm up to a/2=800 µm. The corresponding dose modulation in the polymer gel is visualized via parameter-selective (T2) micro-imaging (MTX: 128x128, nr. of slices: 12, voxel size: 94 x 94 x 1000 μm^3). The T2-maps are converted to dose maps using a calibration table. A very narrow electron beam of diameter d1 = 2mm is obtained using small bores in a lead-plate as absorption mask in an electron-field (E_{max} = 20 MeV), generated on a clinically-used linear-accelerator. Multi-slice R2-(=1/T2) mapping allows for 3D-dosimetry of this fine electron beam. The very high spatial dose-resolution is achieved using a whole-body high-field (B = 3T) MR-scanner (Bruker Mespec S300, Germany) equipped with a customized small bore (d_i = 12 cm) strong gradient-system (G_{max}=200mT/m). For sensitivity reasons a small-sized birdcage resonator (d_i = 15 mm) and signal averaging are used (N_{av} = 16).

Results

The dose distribution below the absorption grid is calculated from the microscopic T2-maps. An image of the first slice inside the polymer gel, nearest to the photon beam entrance, is shown in fig.1. Even the finest slits at 200 µm width can be separated using a pixel size of 94 x 94 μm^2. Thus the very high spatial resolution, possible in MRPD microimaging, is demonstrated. Absolute quantification of the resolution limit is not possible due to missing dosimetric methods capable of resolving such fine dose modulations [3]. As a dosimetric problem the dose spreading of a narrow electron beam in tissue-like material due to electron scattering is investigated by micro-MRPD. The 3D-dose distribution is calculated from the 40 axial T2-slices. A dose coronal projection image is obtained from this 3D-data set and shown in fig. 2.

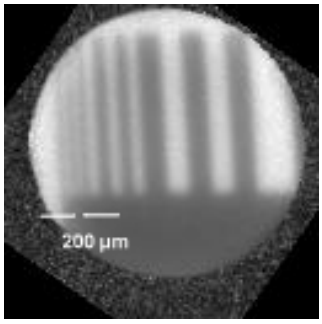

Fig. 1 Image of the dose distribution below the absorption grid. The grid comprises 3 sets of slits with different spatial periods. Even the finest modulation at left (half period a/2 = 200 µm) is visualized indicating the high resolution obtained by micro-MRPD.

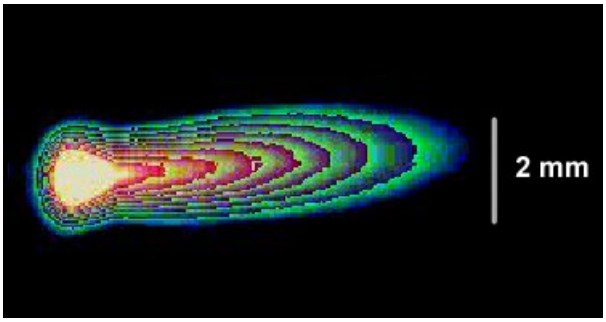

Fig. 2 Coronal projection of the dose distributionof a 2mm electron beam in tissue equivalent polymer gel. Iso-intensity lines are indicated (Voxel size: 199x199x1000 μm^3, MTX: 128x128x40). Dose built- up in the centre and dose fall-off due to the scattering of electrons are visualized.

Conclusion

By micro-MRPD it is possible to visualize dose distributions on a microscopic scale. Due to the 3D-information available by multi-slice MR-micro-imaging 3D-dose distributions may be mapped without performing exorbitant high numbers of single point measurements for instance with diamond- or silicon-diode detectors. Micro-MRPD appears to be well suited for modern methods of fine dose localization as Brachytherapy or micro-multileaf collimation.

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